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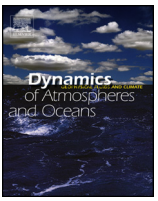

Investigating the coupling between phytoplankton biomass, aerosol optical depth and sea-ice cover in the Greenland Sea

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ABSTRACT

We investigate the relationship between satellite-derived time series for microalgal biomass, measured using remotely sensed chlorophyll-*a* (CHL: mg m^{-3}), aerosol optical depth (AOD) and sea ice cover (ICE) in the Greenland Sea (10° W–10° E, 65–80° N) over the decadal period 2003–2012. Zonal averages for all variables were computed in 5-degree latitude bands. Unlike other regions of the Arctic Ocean, the marginal ice zone in the Greenland Sea is confined to north of 75° N. The CHL time series is characterized by high interannual variability, especially in the northern marginal sea ice zone (MIZ) where variability in sea ice extent is a likely factor. The ten-year climatology shows that CHL increases from March, reaching a seasonal peak in May in the southern sector and in June in the northern sectors. The climatological peak of AOD is achieved in April in all latitude bands, about a month before the peak in CHL. This suggests that the Arctic aerosol burden is strongly affected by continental sources in early spring.

Interestingly, a summer increase in AOD (which succeeds the CHL maximum) is seen in some years. Sea ice extent in early spring is less than 40% in the northern sector in all years. There is considerable interannual variability in both the onset of melt and the

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extent of sea ice loss during summer, with the minimum summer sea ice extent decreasing to almost zero in five of the years. Cross-correlation analyses of the three times series identify a statistically significant relation between CHL and AOD in six of the years in the southern sector, but no correlation between CHL and ICE was found in the northern sector. There is, however, a significant correlation between AOD and ICE time series in the northern sector in four years. High AOD values registered in early spring are most likely of anthropogenic origin, however, peaks later in summer coincident with the phytoplankton bloom and high emissions of biogenic aerosol precursors such as dimethylsulfide and other primary aerosols of marine origin, suggest the summer atmospheric aerosol burden is likely influenced by biogenic emissions.

1. Introduction

Warming in the Arctic is occurring at a greater rate than other places in the Northern Hemisphere, and this trend is expected to continue into the future. During the past century, glaciers have receded throughout the Arctic, terrestrial ecosystems have advanced northward, and perennial Arctic Ocean (AO) sea ice has diminished (Miller et al., 2003; Wang and Overland, 2009). Taken together, the size and speed of the summer sea-ice loss over the last few decades is highly unusual compared to events from previous thousands of years (Kwok and Rothrock, 2009). The impacts of a general loss of perennial sea ice are likely to be far-reaching, and include both feedbacks on the regional heat budget (the "sea-ice albedo effect") and perturbations to the Arctic marine food web (Gabric et al., 2005a; Holland et al., 2006; Post et al., 2013), however, our current knowledge of changes in regional planktonic and benthic systems is surprisingly low (Wassmann et al., 2011).

A critical component of the Arctic marine food web are sea-ice algae which begin to grow in early spring within and underneath the ice, producing a substantial biomass despite very low light intensities (Gradinger, 2009). Pelagic algal blooms, in contrast, normally occur after ice breakup, at high latitudes as late as July–September. Changes in the timing of ice melt and breakup can cause a mismatch between primary and secondary producers, with negative consequences for the entire Arctic marine food web. Zhang et al. (2010) simulate a generally downward trend in summer sea-ice extent during 1988–2007 and a steady decrease in Arctic sea-ice thickness, leading to an increase in simulated photosynthetically active radiation (PAR) at the ocean surface (+43%) and primary production (PP) (+50%) in sea ice covered areas over the 19-year period. In contrast to other parts of the Arctic, the Greenland Sea shows a statistically significant decreasing trend in satellite-derived annual NPP and bloom duration for the 1998–2009 period, which is yet to be explained (Arrigo and van Dijken, 2011). Additionally, Kahru et al. (2011) analyzed a time series of satellite-derived chlorophyll-a for the period 1997–2009 to examine the phenology of the annual phytoplankton bloom and detected statistically significant trends towards earlier phytoplankton blooms in about 11% of the AO area.

Aerosol concentration in the Arctic atmosphere varies seasonally, with continental anthropogenic sources dominant during winter and early spring (Heidam, 1984; Quinn et al., 2007) and local marine biogenic sources contributing to the aerosol burden during summer and autumn (Chang et al., 2011b; Rempillo et al., 2011; Park et al., 2013). A connection between spring and summer sea-ice melt and increased emission of radiatively active biogenic aerosols, such as dimethylsulfide (DMS), has been observed in Antarctic waters (Trevena and Jones, 2012) and predicted for the AO (Gabric et al., 2005a). The nexus between seasonal sea-ice loss in the Arctic and DMS cycling is the subject of a recent review by Levasseur (2013).

Field studies in the Arctic have noted complex inter-relationships between phytoplankton growth, sea-ice melt and the formation and emission of biogenic aerosol precursors such as DMS (Leck et al., 1996; Matrai et al., 2008; Luce et al., 2011). Our aim here is to understand what drives the connection